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Determining Water Quality Index for the Evaluation of Water Quality of River Godavari

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***Abstract*— Water resource experts by and large communicate water quality condition and trends in the language of assessment of individual water quality variables. Despite the fact that this technical lingo is readily understood within the water resources' community it does not readily decipher to communities having profound influence on water resources policy; the general public and policy makers. They anticipate a graspable rejoinder as per their right to be acquainted with the status of the environment. As a solution, a Water Quality Index (WQI) integrate the intricate analytical data and generates a single number stating the quality of a given water body. This enhances the communication with the public and increase public awareness of water quality conditions. Thus it can bridge the gap between water quality monitoring and reporting methods.**

The selected study area is a part of river Godavari system, consisting of seven stations. WQI is found out for the specific purpose of 'irrigation'. Weighting coefficients of the water quality parameters (multi-parameter evaluation) are estimated according to the actual conditions of the river. The flow variations are analyzed as they affect the water quality significantly. The variation in weighting coefficients, importance indices is investigated. The temporal and spatial trends of $WQI_{segment}$ at all stations are evaluated. The overall WQI of the study area falls under grade-IV (for irrigation) viz. medium pollution. The study indicated heavy pollution at Mancherial which hints at a number of industries around.

***Keywords*— Water Quality Index, Grades of Water Quality, $WQI_{segment}$, $WQI_{integral}$, Weighting Coefficient, Influence Degree of Pollutants on Water Quality (IDPWQ), Beyond Standard Frequency Factor, Importance Index, Average Beyond Standard Rate, WQI scores, Conservative Pollutants**

I. INTRODUCTION

"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land" – Luna Leopold (1915-2006), U.S. geomorphologist and hydrologist

Water Quality is an important factor to judge environment changes, which are strongly associated with social and economic development. The evaluation of water in the developing countries has become a critical issue in recent years, especially due to the concern that fresh water will be scarce in near future. Water form a certain source may be good enough for drinking without any treatment but it may not be suitable as a coolant in an industry. It may be good for irrigating certain crops but not for certain other crops.

Expressing water quality is not as easy as expressing water quantity. One rudimentary way to describe the quality of water is to list out the concentrations of constituents which may range from 20-odd common ones to a few hundreds. Comparing the quality of water sources cannot be done easily by comparing the list of constituents of samples. For e.g. a water sample containing six components in 5% higher-than-permissible levels: p^H, hardness, chloride, sulphate, iron and sodium may not be as bad for drinking as another sample with just one constituent – mercury – at 5% higher-than-permissible. It is necessary to point out that the current conditions in the manual processing to a large number of analytical data practically prevent faster interpretation of results.

As a solution, Water Quality Indices aim at giving a 'single value' to the water quality of a source on the basis of one or other system which translates the list of constituents and their concentrations present in a sample/samples into a single value.

A. Definition and significance of Water Quality Index (WQI)

Water Quality Index is a form of average derived by relating a group of variables to a common scale and combining them into a single number. A WQI summarizes information by combining several sub-indices of constituents (quality variables) into a *univariate expression*. The group should contain the most significant parameters of the dataset, so that the index can describe the overall position and reflect change in a representative manner.

Water resource professionals generally communicate water quality status and trends in terms of the evaluation of individual water quality variables. While this is readily understood within the water resources community, it does not readily get translated to communities having profound influence on water resources and related policies: the

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general public and policy makers. Increasingly these communities expect a comprehensible response to their right to know about the status of the environment.

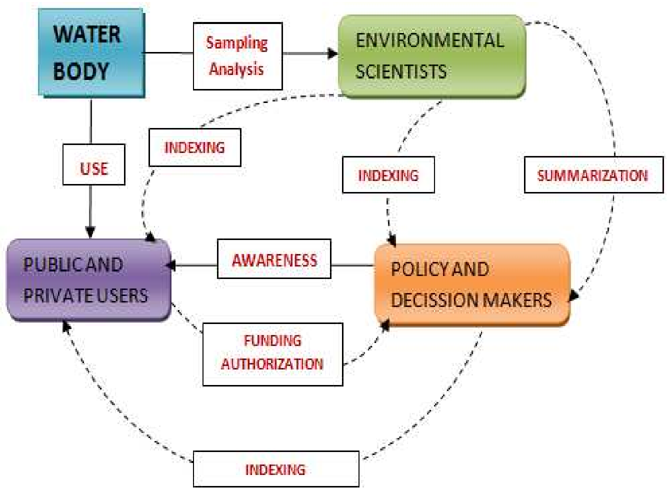

Fig. 1 Network for Communication of Water Quality

Water Quality Index can bridge the gap between water quality monitoring and reporting methods. Integrative index, which provide a single number that can express the relative level of impairment of a water body and how the quality has changed through time, is particularly useful for communicating information to general public. WQI provides cost-effective water quality assessment ways as well as the possibility of evaluating trends.

II. The Study Area and Objectives

B. Stations in the Study Area

The study area consists of the following water quality monitoring stations on River Godavari.

1. Mancherial, Perur and Polavaram
2. Nowrangpur, Jagdalpur and Pathagudem on the stream Indravathi of tributary Indravathi
3. Konta on the stream Sabari of tributary Sabari

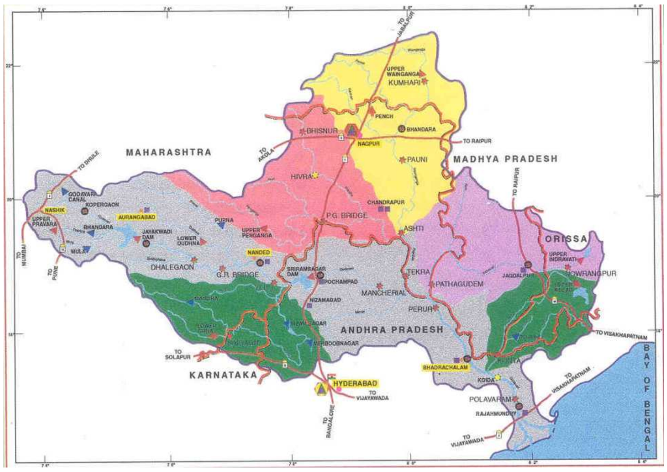

Fig. 2 River Godavari Basin

The upstream and the downstream locations are located using the basin map of river Godavari.

TABLE I
A SUMMARY OF WATER QUALITY STATIONS IN THE STUDY AREA

Number	Station Name	Details of station		
		Latitude	Longitude	Area in Hectares
1	Polavaram	17°14’45’’	81°39’35’’	307800
2	Perur	18°33’00’’	80°22’00’’	268200
3	Mancherial	18°50’00’’	79°27’00’’	102900
4	Konta	17°48’00’’	81°23’00’’	19550
5	Pathagudem	18°49’00’’	80°21’00’’	40000
6	Jagdalpur	19°06’30’’	82°01’30’’	7380
7	Nowrangpur	19°12’00’’	82°31’00’’	3545

C. Data base for the study

The water quality data for the period – January 1996 to May 2004 is obtained from the Hyderabad branch of Central Water Commission (CWC). Standard methods are being adopted at all the sites for collecting the discharge and water quality data. Observed data at the field station is entered or computed in different formats prescribed for the purpose and later processed at various levels before publishing the *water year book*. The water year is from 1st June of one calendar year to 31st May of another calendar year and covers the complete hydrological cycle. Discharges and water quality data given are observed at 8:00 hour. The water quality data is monitored at an interval of 10 days.

D. Objectives of The Study

River Godavari is the largest river in South India. Many a factor such as urbanization, industrialization, improper disposal of industrial, municipal and agricultural wastes

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causes deterioration of the water quality of the river. Evaluation of river water quality is very important to see the feasibility of using the river water as a source for various activities such as irrigation, municipal water supply, recreation etc.

The main objectives of are:

- To find WQI for the purpose of 'irrigation'
- To evaluate the temporal and spatial variations of $WQI_{segment}$ for each of the seven stations in the study area
- To assess the temporal variations of $WQI_{integral}$ for the entire study area.

III. METHODOLOGY

The methodology of the analysis is adopted from the paper "Determination of weighting coefficients in Water Quality Index method and its application in river water quality evaluation" by Tian Y., Li H., Zhou Y. and Wang Y., The College of Environmental Science and Engineering, Tianjin University, China. The WQI is identified according to the criterions of Environmental Quality Standards for Surface Water (EQSSW) [GB3838-2002]. Considering that every parameter has different impacts on water environment of a river, weighting factor of the parameters of interest should be included in the evaluation process.

Water Quality Index =

$$\sum_{i=1}^{n} \omega_i . \frac{C_i}{S_i} \text{ -- Equation – [1]}$$

where C_i is the measured concentration; S_i is the water quality standard; 'n' is the number of evaluated pollutants; ω_i is the weighting coefficient of the pollutant (parameter) 'i' in the river.

E. Grades and classification of Water Quality Index

TABLE II
GRADES OF WATER QUALITY INDEX

WQI	Grade	Description
< 0.2	I	Clean
0.2 - 0.4	II	Less Clean
0.4 - 0.7	III	Light Pollution
0.7 - 1.0	IV	Medium Pollution
1.0 - 2.0	V	Heavy Pollution
> 2.0	VI	Very Heavy Pollution

The WQI is classified into $WQI_{segment}$ and $WQI_{integral}$. $WQI_{segment}$ is used to judge the pollution of different sections in a river (equation-[1]) where as $WQI_{integral}$ is used to evaluate the integral comprehensive pollution condition of a river which is calculated by the following equation.

$WQI_{integral}$ =

$$\sum_{i=1}^{n} \omega_i . \sum_{j=1}^{m} \frac{C_{ij}}{S_i} \text{ -------------------------------------- Equation – [2]}$$

where m is the number of evaluated sections.

Weighting coefficients of all monitoring pollutants are identified according to the Influence Degree of Pollutants on Water Quality (IDPWQ) and beyond-standard frequency factors of the pollutants.

$$\omega_i = \frac{1}{2}\left(\frac{r_i}{\sum r_i} + \frac{p_i}{\sum p_i}\right) \text{ ----------------------------- Equation – [3]}$$

$$\sum \omega_i = 1$$

where r_i = The importance or influence index of pollutant 'i'; p_i is the average beyond standard rate of pollutant 'i' in all observations.

The monitoring parameters of a river can be classified as follows:

- First Class: Slightly harmful, degradable or volatile e.g. Chloride, DO etc.

$$r_i = \frac{C_i}{S_i} \qquad (i = 1,2,\ldots\ldots.,n_1)$$

- Second Class: More harmful or more difficult to be degraded than first class e.g. Cu, Zn etc.

$$r_i = \frac{1}{2}\left(\frac{C_i}{S_i} + \left(\frac{C_i}{S_i}\right)^{2exp\, lsgn\, (\theta\,)l}\right) \qquad (i = 1,2,\ldots\ldots.,n_2)$$

- Third Class: Most harmful e.g. Hg, Cd, As, Pb etc.

$$r_i = \frac{1}{2}\left(\frac{C_i}{S_i} + \left(\frac{C_i}{S_i}\right)^{2exp\, lsgn\, (\theta\,)l} + \left(\frac{C_i}{S_i}\right)^{3exp\, lsgn\, (\theta\,)l}\right) \qquad (i = 1,2,\ldots\ldots\ldots,n3)$$

where $\theta = [(C_i/S_i) -1]$
$sgn(\theta) = 1$ if $\theta > 0$;
$= -1$ if $\theta < 0$;
$= 0$ if $\theta = 0$

n_1 is the number of the first class pollutants; n_2 is the number of the second class pollutants; n_3 is the number of the third class pollutants

------------------------------------ Equation – [4]

Equation – [4] shows that the influence degrees of virulent and toxic pollutants are strengthened through amplification of pollution intensity indices in the second and third classes,

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which objectively reflects influence degrees of different pollutants to water quality. This method is one of the latest and efficient. It was used to evaluate the spatial and seasonal changes of water quality of a river in North China. Based on the case study of the river, the evaluation method was proven to be practical.

F. Purpose, classification and calculations

The Water Quality Indices are found out for the specific purpose 'irrigation'. Indian standards of water for irrigation are taken into consideration. Nine parameters (pollutants) are considered, out of which chloride, sulphate, p^H (general), Electrical Conductivity (EC, general), percentage of sodium (Na %), and Sodium Absorption Ratio (SAR) are classified as first class pollutants whereas Fluoride, Boron, and Iron are classified under second class. Third class pollutants are infrequent and hence are not included.

Microsoft excel is the spread sheet tool used for carrying out the basic calculations including the other necessary ones and for drawing all the required graphs. MS Excel is efficient and user friendly. During the study period, 1627 readings (observations) for each of the nine parameters are considered. In case the beyond-standard frequency factor doesn't exist ($\Sigma P_i = 0$), then the influence degree alone becomes the weighting coefficient of a pollutant of any class. In such cases the formula for finding weighting coefficient has been modified accordingly. It has been checked and found out that $\Sigma\, \omega_i$ is equal to 1.

IV. Results and Discussion

G. Influence of Flow Variations on WQI

Prior to WQI development, flow variations are taken into consideration for improving overall trends. Year wise and spatial WQI scores are developed for better statistical analysis. The variations Before Rainy Season (BRS) are compared with the respective variations In Rainy Season (IRS).

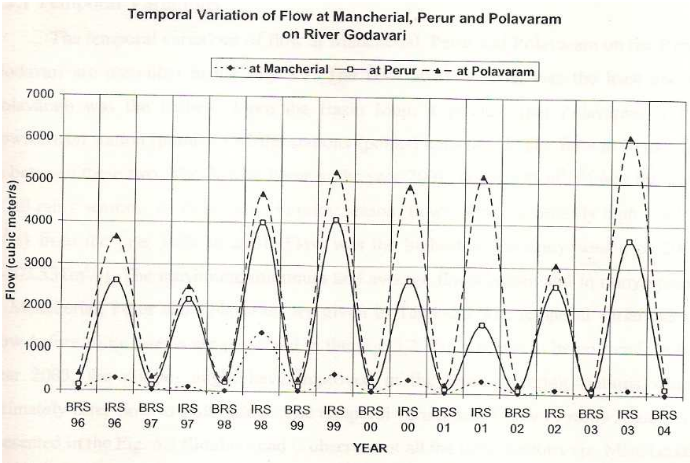

Fig. 3 Temporal Variations of Flow (cumec) at Mancherial, Perur and Polavaram

As the flow variations influence the water quality significantly, classification based on flows is essential. Especially in the tropical rivers where rainfall influences water quality, study of seasonal flow variations is quite useful. At the stations Mancherial, Perur and Polavaram, large variations are observed between the dry and wet flows corresponding respectively to the pre-monsoon and monsoon seasons. The flow variations range between 20 – 380 cumec for Mancherial, 130 – 3000 cumec for Perur, and 300 – 4000 cumec for Polavaram. The flows in rainy season are at least 10 – 20 times of that in dry period (season). The flows in river are responsible for dilution of pollutants and hence the flow variations influence the water quality parameters. To overcome the effects of flow variations WQI are developed separately for rainy and dry seasons and then compared.

An increase in trend for flows from upstream to downstream is obvious because there are no major storage structures in this stretch of the river. The increase in flow influences the velocity of flow and mixing phenomena. Stream velocity has a two-fold effect on the water quality parameters and thus on WQI. Increase in velocity to a certain level aid complete mixing and reduction in time of travel for the pollutant to reach downstream monitoring station from upstream monitoring station. Mixing and turbulence caused can influence the decay process especially for the non-conservative pollutants. If conservative pollutants are of diffuse origin, the downstream water quality is significantly affected especially during the monsoon season.

H. Importance Indices and Weighting Coefficients

The importance indices are (r_i) of the pollutants for irrigation are determined by equation – [4].

TABLE III
Importance Indices of Parameters

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Parameter	Importance Index	
	Maximum	Minimum
Chloride	0.2507	0.00282
Sulphate	0.10208	2.08×10^{-5}
p^H (general)	1.64773	1.0069
Electrical Conductivity	0.30222	0.01511
Sodium percentage	1.1566	0.03356
Sodium Absorption Ratio	0.10969	0.00158
Fluoride	111.97	0.02186
Boron	0.44017	0.00211
Iron	0.47955	0.0036

TABLE IV
WEIGHTING COEFFICIENTS OF PARAMETERS

Parameter	Importance Index	
	Maximum	Minimum
Chloride	0.03726	0.000214
Sulphate	0.04589	5.2×10^{-6}
p^H (general)	0.927166	0.005073
Electrical Conductivity	0.097583	0.000878
Sodium percentage	0.599513	0.001005
Sodium Absorption Ratio	0.029468	3.55×10^{-5}
Fluoride	0.990245	0.007544
Boron	0.227791	7.27×10^{-5}
Iron	0.211391	0.000276

Very high importance index of fluoride (111.97) is due to its very high concentration (2.698 mg/l) at Mancherial on 15-April-1997 where the $\omega_i[F^-]$ is 0.990245 and $WQI_{segment}$ is 2.6796. The fluoride concentration exceeded the specified limit (1mg/l) at 150 observations, over the study period, ranging from 2.698 to 1.007 mg/l. The other parameters are within the specified limits. At Perur, the Fluoride concentration exceeded 1 mg/l at 16 observations ranging from 1.41 to 1.01 mg/l. At Konta, at one instance i.e. on 23-Jan-1996, fluoride concentration was very high (2.09 mg/l) where the $r_i[F^-]$ is 28.62319, $\omega_i[F^-]$ is 0.978059 and $WQI_{segment}$ is 2.06438. The very low importance index of sulphate (2.08×10^{-5}) is due to its low concentration (0.01 mg/l) at Jagdalpur at 12 observations during the period of 23-Jan-1996 to 12-May-1998 and the weighting coefficient is the least i.e. 5.2×10^{-6} at 21-Feb-1997.

The importance indices and weighting coefficients of p^H and fluoride are significantly higher than those of the other parameters. Even though the general water quality is of GRADE-IV, on a few situations water quality is rated as GRADE-V, primarily due to increase in seasoned runoff. For some sites under consideration, the WQI scores are lower than those of the previous years because of the changes in local weather conditions. More rain resulted in increased surface runoff and increased movement of materials from land to water due to catchment specific characteristics of some areas. Water quality tends to be poorer downstream of areas with significant urban, industrial, or agricultural development. However in the recent years substantial improvements have been made to water quality downstream as a result of improved point source control. This is reflected by amelioration of index values.

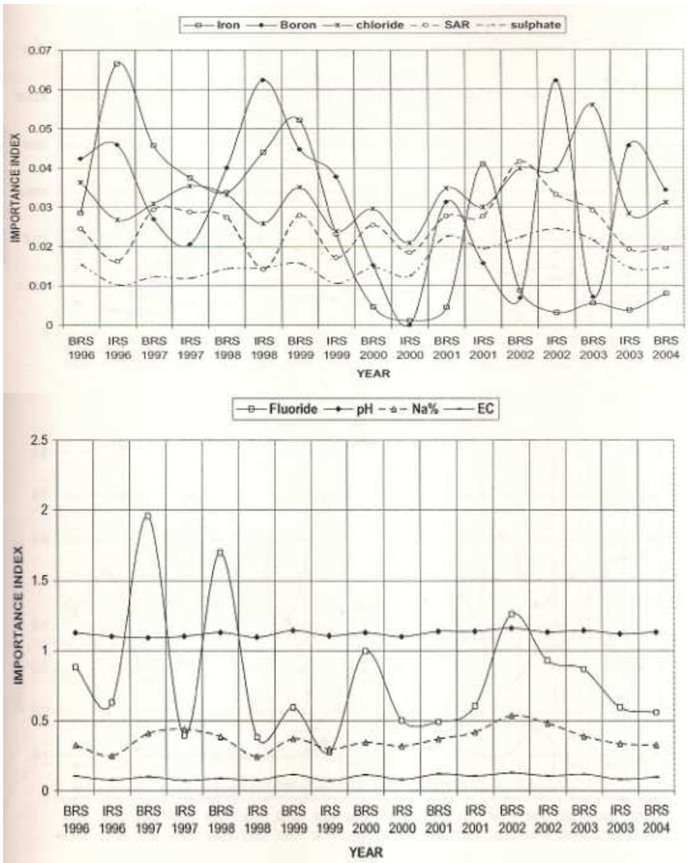

Fig. 4 Temporal Variation of Importance Indices

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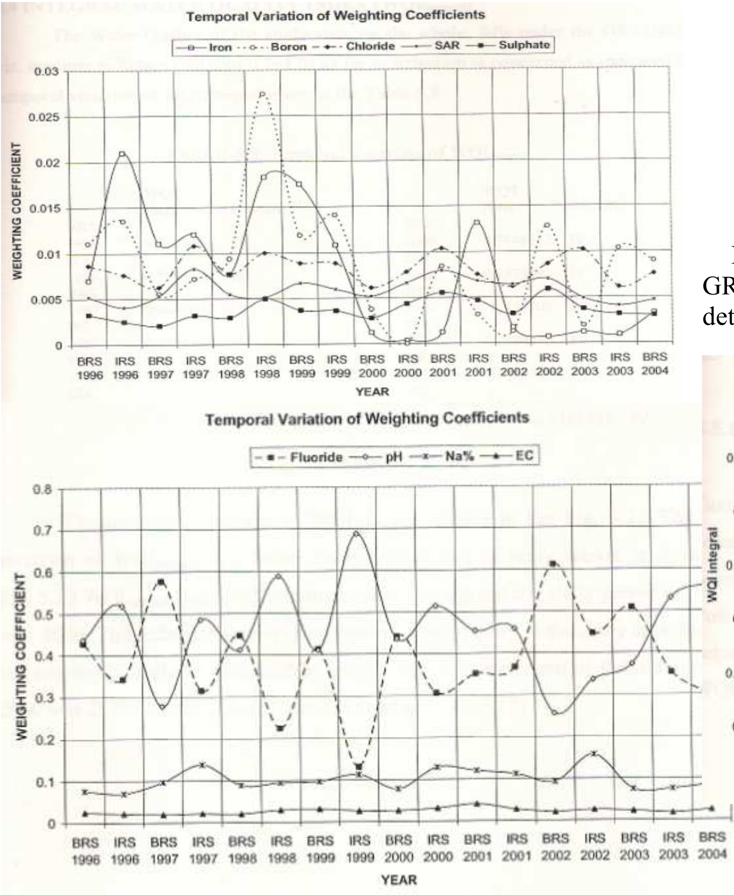

Fig. 5 Temporal Variation of Weighting Coefficients

I. Integral Water Quality Index ($WQI_{integral}$)

TABLE V
TEMPORAL VARIATIONS OF $WQI_{INTEGRAL}$

Period	$WQI_{integral}$	GRADE
BRS 1996	0.7759464	IV
IRS 1996	0.7883622	IV
BRS 1997	0.6440076	III
IRS 1997	0.7058838	IV
BRS 1998	0.7161621	IV
IRS 1998	0.7521166	IV
BRS 1999	0.7058413	IV
IRS 1999	0.8228196	IV
BRS 2000	0.7446613	IV
IRS 2000	0.7329797	IV
BRS 2001	0.724702	IV
IRS 2001	0.7364743	IV
BRS 2002	0.729586	IV
IRS 2002	0.7791903	IV
BRS 2003	0.7640233	IV
IRS 2003	0.8434509	IV
BRS 2004	0.8188797	IV

From table V, it's evident that $WQI_{integral}$ falls under GRADE-IV. Even though of the same grade, water quality deteriorated in the rainy season (monsoon period).

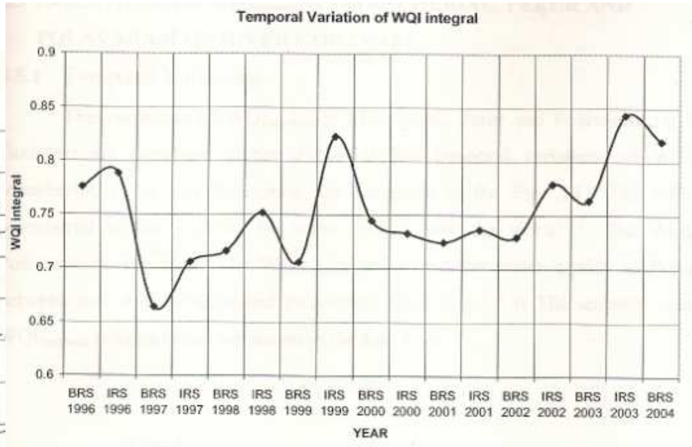

Fig. 6 Temporal Variation of $WQI_{integral}$

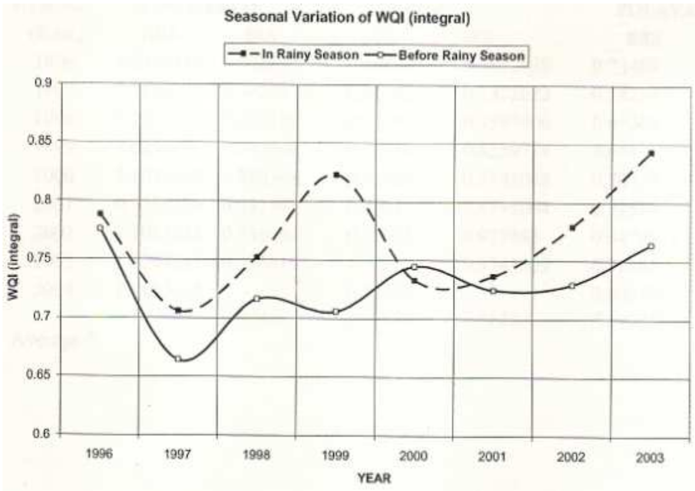

Fig. 7 Seasonal Variation of $WQI_{integral}$

J. Variations of $WQI_{segment}$ at Mancherial, Perur and Polavaram on River Godavari

1. Temporal Variations

TABLE VI
TEMPORAL VARIATIONS OF $WQI_{SEGMENT}$

YEAR	STATION					
	MANCHERIAL		PERUR		POLAVARAM	
	BRS	IRS	BRS	IRS	BRS	IRS
1996	1.044012	1.046553	0.80697	0.787263	0.74469	0.81554
1997	1.268073	0.942237	0.80382	0.73726	0.58254	0.6937
1998	1.22170	0.85316	0.71943	0.758741	0.66365	0.72945
1999	1.029849	0.893546	0.78936	0.855977	0.661	0.84369
2000	1.101860	0.930348	0.82988	0.718109	0.70779	0.71968
2001	0.935527	0.957597	0.80055	0.875106	0.73519	0.71803
2002	1.081943	0.936084	0.79983	0.917885	0.64791	0.79467
2003	1.179785	0.995619	0.8067	0.874501	0.712291	0.77582
2004	1.11525	--	0.83524	---	0.80079	---

BRS is 'before rainy season'; IRS is 'in rainy season'. The water at Mancherial is highly polluted is as indicated by $WQI_{segment}$ (highest). In general, Water quality is improved in the rainy season at Mancherial. $WQI_{segment}$ at Polavaram is the least. $WQI_{segment}$ and hence the water quality at Perur was in between that at Mancherial and Polavaram.

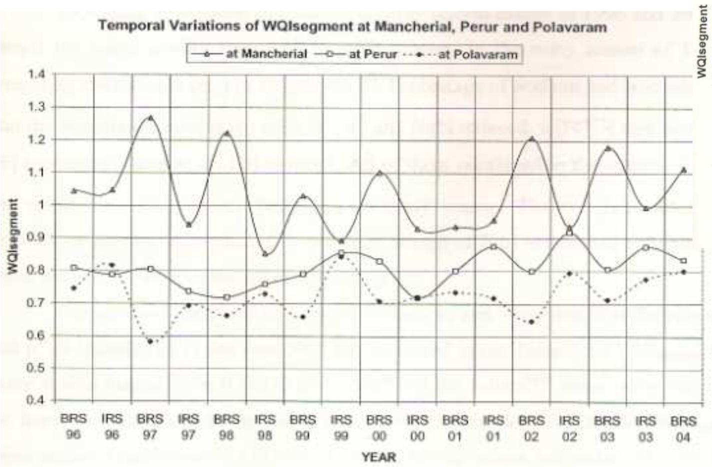

Fig. 8 Temporal Variations of $WQI_{segment}$ at Mancherial, Perur, and Polavaram

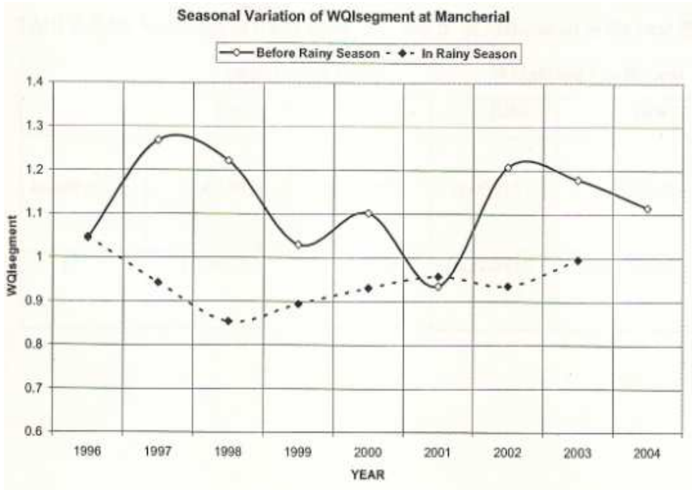

Fig. 9 Seasonal Variation of $WQI_{segment}$ at Mancherial

$WQI_{segment}$ at Mancherial reduced in rainy season except in 1996 and 2001. So the water quality in general improved in rainy season.

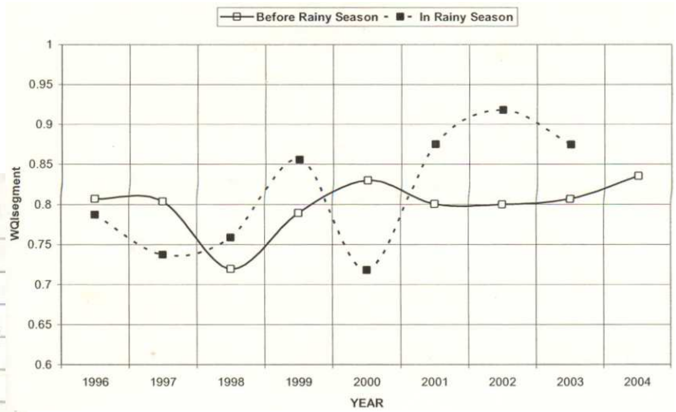

Fig. 10 Seasonal Variation of $WQI_{segment}$ at Perur

At Perur, there appears to be no general trend.

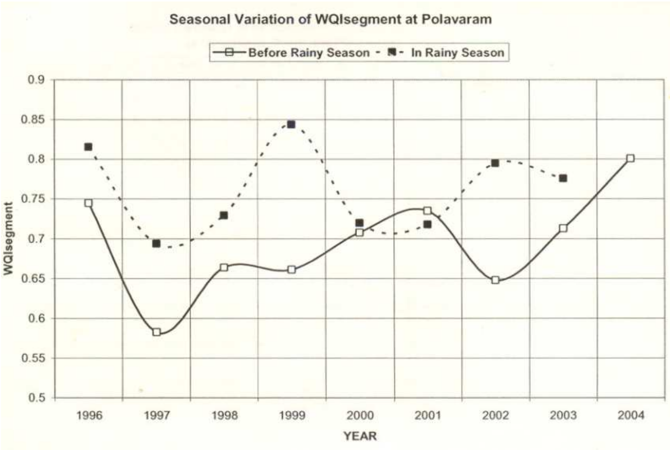

Fig. 11 Seasonal Variation of $WQI_{segment}$ at Polavaram

At Polavaram, there is a general trend of increment or augment of $WQI_{segment}$.

2. Spatial Variations at Mancherial, Perur and Polavaram

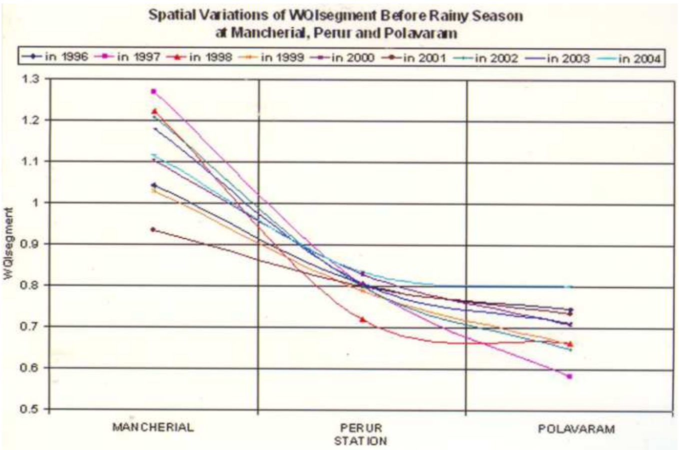

Fig. 12 Spatial Variations of $WQI_{segment}$ before rainy season at Mancherial, Perur and Polavaram

Before Rainy Season: There is specific concave shaped trend. At Mancherial, $WQI_{segment}$ ranged from 0.935527 (GRADE-IV) to 1.268073 (GRADE-V). At Perur, $WQI_{segment}$ ranged from 0.71943 to 0.83524 (GRADE-IV). At Polavaram, $WQI_{segment}$ ranged from 0.582544 (GRADE-III) to 0.801 (GRADE-IV).

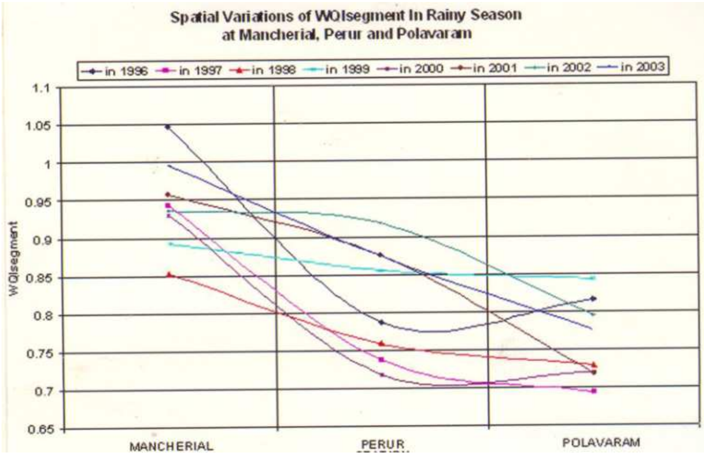

Fig. 13 Spatial Variations of $WQI_{segment}$ in rainy season at Mancherial, Perur and Polavaram

In Rainy Season: There are both concave and convex shaped trends. At Mancherial, $WQI_{segment}$ ranged from 0.8532 (medium pollution) to 1.0466 (heavy pollution). At Perur, $WQI_{segment}$ ranged from 0.71811 to 0.9179 (GRADE-IV). At Polavaram, $WQI_{segment}$ ranged from 0.69371 (GRADE-III) to 0.843692 (GRADE-IV). As Polavaram is the downstream station, deterioration of WQI at Polavaram is much more significant.

Similarly the trends at the other stations are analysed.

V. CONCLUSIONS

- The WQI used provides a non-expert with an easy way of understanding the overall water quality.
- The quality of water (integral) at the monitoring sites during the study period was generally of GRADE-IV
- At Mancherial, the industrial activity dominates leading to deteriorating WQI.
- Finding out the necessary spatial variations with the help of flow data wherever available ensured that the results are more reasonable and objective than the traditional assessment methods.
- It is important to monitor water quality over a period of time in order to detect changes and convey it to the stake holders through WQI.

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